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Transforming an Extended-Cavity Diode Laser into a Frequency Reference at 1.39 Microns by Noise Immune Cavity Enhanced Optical Heterodyne Molecular Spectroscopy (NICE-OHMS)

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Extended-Cavity Diode Lasers (ECDL) generally have emission line-widths between 100 kHz up to 1 MHz, over 1 ms of observation time. The frequency jitter of these lasers (when coupled with a frequency discriminator with a relatively high quality factor) can give rise to amplitude fluctuations thereby affecting the signal-to-noise ratio, limiting the precision of the experiments involved. Hence, phase-and-frequency noise reduction of an ECDL is vital for precision laser spectroscopy. Galzerano et al reported the use of first-derivative lamb-dip spectroscopy for the absolute frequency stabilization of an ECDL across a sub-Doppler molecular transition [1]. In this work we report on the first use of NICE-OHMS for stabilizing the frequency of an ECDL across the centre of a sub-Doppler $H_2{}^{18}O$ line at 1.39 um. Invented by J.L.Hall, NICE-OHMS consists of a proper combination of frequency modulation spectroscopy with cavity enhanced absorption spectroscopy [2]. Our stabilization system involves three servo loops. The first stage involves locking the laser frequency to a high finesse cavity resonance frequency by Pound Drever Hall servo loop. The second stage involves locking a pair of sidebands to the cavity free-spectral-range splitting frequency by using the DeVoe Brewer method. The final stage involves locking the cavity resonance across the centre of a sub-Doppler NICE-OHMS signal, observed by the heterodyne detection of the cavity output when the cavity is filled with 98% ^{18}O enriched sample. The line-width of our frequency reference turns out to be 6.89 kHz. The Allan deviation analysis of the error signal used for absolute frequency stabilization yields an in-loop relative stability of 4 x 10^{-14}. The former corresponds to a line-width reduction by a factor 220 with respect to the free running line-width while the latter corresponds to an improvement by a factor of 4.43 with respect to the previously developed frequency reference [3,4].